

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
22 May 2003 (22.05.2003)

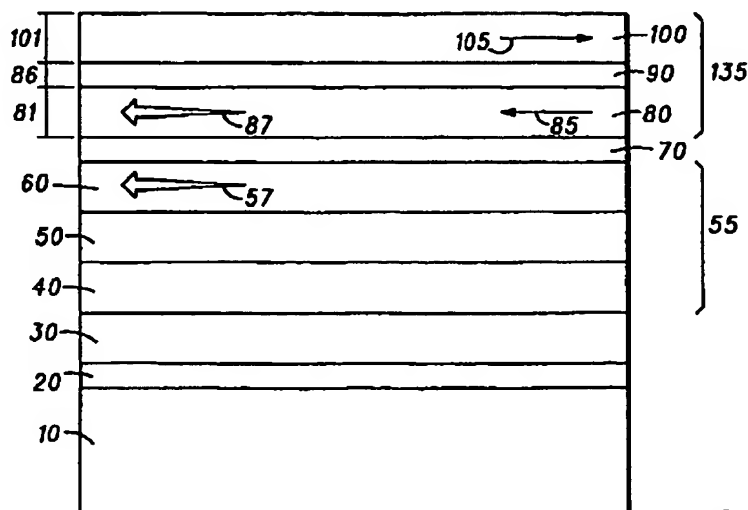
PCT

(10) International Publication Number
WO 03/043018 A1

- (51) International Patent Classification⁷: **G11C 11/16**, **H01F 10/32**, **41/30**
- (21) International Application Number: **PCT/US02/31946**
- (22) International Filing Date:
24 September 2002 (24.09.2002)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
09/978,860 16 October 2001 (16.10.2001) US
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- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).
- Published:
— with international search report

[Continued on next page]

(54) Title: MAGNETORESISTANCE RANDOM ACCESS MEMORY FOR IMPROVED SCALABILITY



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(57) Abstract: A scalable magnetoresistive tunneling junction memory cell (5) comprising a fixed ferromagnetic region (55) having a magnetic moment vector fixed in a preferred direction in the absence of an applied magnetic field, an electrically insulating material (70) positioned on the fixed ferromagnetic region to form a magnetoresistive tunneling junction, and a free ferromagnetic region (135) having a magnetic moment vector oriented in a position parallel or anti-parallel to that of the fixed ferromagnetic region. The free ferromagnetic region includes N ferromagnetic layers (80, 100) that are anti-ferromagnetically coupled, where N is an integer greater than or equal to two. The number N of ferromagnetic layers can be adjusted to increase the effective magnetic switching volume of the MRAM device.

Magnetoresistance Random Access Memory for
Improved Scalability

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FIELD OF THE INVENTION

This invention relates to semiconductor memory
devices.

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More particularly, the present invention relates to
semiconductor random access memory devices that utilize a
magnetic field.

BACKGROUND OF THE INVENTION

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Memory devices are an extremely important component
in electronic systems. The three most important
commercial high-density memory technologies are SRAM,
DRAM, and FLASH. Each of these memory devices uses an
20 electronic charge to store information and each has its
own advantages. SRAM has fast read and write speeds, but
it is volatile and requires large cell area. DRAM has
high density, but it is also volatile and requires a
refresh of the storage capacitor every few milliseconds.
25 This requirement increases the complexity of the control
electronics.

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FLASH is the major nonvolatile memory device in use today. Typical non-volatile memory devices use charges trapped in a floating oxide layer to store information. Drawbacks to FLASH include high voltage requirements and slow program and erase times. Also, FLASH memory has a poor write endurance of 10^4 - 10^6 cycles before memory failure. In addition, to maintain reasonable data retention, the thickness of the gate oxide has to stay above the threshold that allows electron tunneling, thus restricting FLASH's scaling trends.

To overcome these shortcomings, new magnetic memory devices are being evaluated. One such device is magnetoresistive RAM (hereinafter referred to as "MRAM"). MRAM has the potential to have speed performance similar to DRAM. To be commercially viable, however, MRAM must have comparable memory density to current memory technologies, be scalable for future generations, operate at low voltages, have low power consumption, and have competitive read/write speeds.

For an MRAM device, the stability of the memory state, the repeatability of the read/write cycles, and the memory element-to-element switching field uniformity are three of the most important aspects of its design characteristics. A memory state in MRAM is not maintained by power, but rather by the direction of the

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magnetic moment vector. Storing data is accomplished by
applying magnetic fields and causing a magnetic material
in a cell to be magnetized into either of two possible
memory states. Recalling data is accomplished by sensing
5 the electrical resistance, which differs for the two
states. The magnetic fields for programming are created
by passing currents through conductive lines external to
the magnetic structure or through the magnetic structures
themselves.

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Conventional MRAM devices rely on the bit shape with
aspect ratio to create a shape anisotropy that provides
the switching field. As the bit dimension shrinks, three
problems occur. First, the switching field increases for
15 a given shape and film thickness, requiring more current
to switch. Second, the total switching volume is reduced
so that the energy barrier for reversal, which is
proportional to volume and switching field, is also
reduced. The energy barrier refers to the amount of
20 energy needed to switch the magnetic moment vector from
one state to the other. The energy barrier determines
the data retention and error rate of the MRAM device and
unintended reversals can occur due to thermal
fluctuations if the barrier is too small. Finally,
25 because the switching field is produced by shape, the
switching field becomes more sensitive to shape

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variations as the bit shrinks in size. With photolithography scaling becoming more difficult at smaller dimensions, MRAM devices will have difficulty maintaining tight switching distributions.

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It would be highly advantageous, therefore, to remedy the foregoing and other deficiencies inherent in the prior art.

10 Accordingly, it is an object of the present invention to provide a new and improved magnetoresistive random access memory device.

15 It is an object of the present invention to provide a new and improved magnetoresistive random access memory device which can be scaled while keeping the switching field nearly constant.

20 It is another object of the present invention to provide a new and improved magnetoresistive random access memory device which has a controllable magnetic switching volume.

25 It is a further object of the present invention to provide a new and improved magnetoresistive random access memory device which has a controllable energy barrier to minimize the bit error rate of the device.

It is an object of the present invention to provide a new and improved magnetoresistive random access memory device which can be fabricated using conventional photolithography processing.

It is another object of the present invention to provide a new and improved magnetoresistive random access memory device which has a switching field that is less dependant on shape.

SUMMARY OF THE INVENTION

To achieve the objects and advantages specified above and others, a scalable magnetoresistive tunneling junction memory (hereinafter referred to as "MRAM") device is disclosed. The MRAM device includes a substrate onto which a fixed magnetic region is positioned. An electrically insulating material of sufficient thickness to act as a electron tunneling barrier is then positioned on the fixed magnetic region and a free magnetic region is positioned on the electrically insulating material. The fixed magnetic region adjacent to the tunneling barrier has a resultant magnetic moment vector that is fixed in a preferred direction.

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In the preferred embodiment, the free magnetic region includes a synthetic anti-ferromagnetic (hereinafter referred to as "SAF") layer material. The synthetic anti-ferromagnetic layer material includes N anti-ferromagnetically coupled layers of a ferromagnetic material where N is an integer greater than or equal to two. Further, the N layers define a magnetic switching volume that can be adjusted by changing N. In the preferred embodiment, the N ferromagnetic layers are anti-ferromagnetically coupled by sandwiching an anti-ferromagnetic coupling spacer layer between each adjacent ferromagnetic layer.

In the preferred embodiment, the total net magnetic moment vector is comprised of the vector sum of the each N sub-layer magnetic moment vectors. Because each sub-layer is anti-ferromagnetically coupled to its neighboring layer, there are two antiparallel directions the sub-layer moments can point in zero magnetic field. The total moment is therefore determined by the difference of M_1 and M_2 , where M_1 and M_2 are the total sub-layer moments in each direction, respectively. The magnetic moment vectors are usually oriented antiparallel by the coupling of the anti-ferromagnetic coupling spacer layer. Anti-ferromagnetic coupling is also generated by the magnetostatic fields of the layers in the MRAM structure. Therefore, the spacer layer need

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not necessarily provide any additional antiferromagnetic coupling beyond eliminating the ferromagnetic coupling between the two magnetic layers.

5 The magnetic moment vectors in the ferromagnetic layers can have different magnitudes to provide a resultant magnetic moment vector given by $\Delta M = (M_2 - M_1)$ and a sub-layer magnetic moment fractional balance ratio,
$$M_{br} = \frac{(M_2 - M_1)}{(M_2 + M_1)} = \frac{\Delta M}{M_{total}},$$
 where $M_{total} = M_1 + M_2$ is the total
10 moment of the N layers. The resultant magnetic moment vector of the N -layer structure is free to rotate with an applied magnetic field. In zero field the resultant magnetic moment vector will be stable in a direction, determined by the magnetic anisotropy, which is either
15 parallel or anti-parallel with respect to the resultant magnetic moment vector of the fixed magnetic region.

 The current through the MRAM device depends on the tunneling magnetoresistance, which is governed by the
20 relative orientation of the magnetic moment vectors of the free and fixed magnetic regions directly adjacent to the tunneling barrier. If the magnetic moment vectors are parallel, then the MRAM device resistance is low and a voltage bias will induce a larger current through the
25 device. This state is defined as a "1". If the magnetic moment vectors are anti-parallel, then the MRAM device

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resistance is high and an applied voltage bias will
induce a smaller current through the device. This state
is defined as a "0". It will be understood that these
definitions are arbitrary and could be reversed, but are
5 used in this example for illustrative purposes. Thus, in
magnetoresistive memory, data storage is accomplished by
applying magnetic fields that cause the magnetic moment
vectors in the MRAM device to be orientated either one of
parallel and anti-parallel directions relative to the
10 magnetic moment vector in the fixed reference layer.

The number N of ferromagnetic layers can be adjusted
to increase the magnetic switching volume of the free
magnetic region. By increasing the magnetic switching
15 volume, the energy barrier required to inadvertently
reverse the magnetic moment vectors is increased. The
effect of the increased energy barrier is to decrease the
data retention error rate due to inadvertent reversals
caused by thermal fluctuations. Consequently, the
20 stability of the memory state is increased. The addition
of ferromagnetic layers can be such that there is no
change in the sub-layer magnetic moment balance ratio M_{br}
and the switching field remains constant for a circular
bit shape. Hence, the total energy barrier is increased
25 since each anti-ferromagnetically coupled ferromagnetic
layer must overcome its intrinsic anisotropy to reverse,
thereby increasing the magnetic switching volume without

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increasing the required switching current. Therefore,
the MRAM device can be scaled to smaller lateral
dimensions and the magnetic switching volume can be kept
constant or adjusted to a desired value by adding more
5 anti-ferromagnetically coupled ferromagnetic layers while
maintaining a constant sub-layer moment balance ratio.

In the preferred embodiment, the MRAM device is
circular in shape so that there is no contribution to the
10 switching field from shape anisotropy. In this
configuration, a parameter that predominantly sets a
switching field is the material's induced magnetic
anisotropy, H_k . For typical materials such as NiFeCo, H_k
is only about 20 Oe, which is undesirable for MRAM device
15 operation. If a SAF N-layer structure is included in the
free region, then the anisotropy and switching field, H_{sw} ,
is amplified depending on the sub-layer magnetic moment
fractional balance ratio M_{br} such that:

$$H_{sw} = \frac{(M_2 + M_1)}{(M_2 - M_1)} \cdot H_k = \frac{H_k}{M_{br}},$$

20 where M_1 , M_2 are the total sub-layer magnetic moments in
each direction of the N-layer structure, respectively.
The increase in the switching field is a result of the
smaller resultant magnetic moment vector becoming a
smaller handle for the external magnetic field to rotate
25 all of the spins in the N ferromagnetic layers. Hence,

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the closer in magnitude that the opposing magnetic
moments are to each other, the higher the effective
switching field. Thus, the switching field can be
adjusted to a reasonable value through the control of the
5 induced H_k and the sub-layer magnetic moment balance ratio
 M_{br} . The shape sensitivity is decreased since the
circular shape is not the main source of the switching
field. Also, the diminished resultant magnetic moment
vector further reduces the effect of shape variations
10 since the effective magnetic charges at the shape edges
are much smaller than for a single layer film of
comparable thickness.

BRIEF DESCRIPTION OF THE DRAWINGS

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The foregoing and further and more specific objects
and advantages of the instant invention will become
readily apparent to those skilled in the art from the
following detailed description of a preferred embodiment
20 thereof taken in conjunction with the following drawings:

FIG. 1 is a sectional view of a magnetoresistive
random access memory device with improved scalability;
and

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FIG. 2 is a graph illustrating the coercivity of a bulk free layer film verses the thickness of one ferromagnetic layer in a N-layer structure with the other layer held at a constant thickness of 40 Å.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

10

Turn now to FIG. 1, which illustrates a simplified sectional view of a scalable magnetoresistive tunneling junction memory cell 5 in accordance with the present invention. The scalable magnetoresistive tunneling junction memory cell 5 includes a supporting substrate 10 onto which a seed layer 20 is positioned. Supporting substrate 10 may be, for example, a semiconductor substrate or wafer and semiconductor control devices may then be formed thereon. Seed layer 20 is formed on supporting substrate 10 to aid in the formation and operation of the remaining layers of material. An anti-ferromagnetic layer 30 is then positioned on seed layer 20 and includes, for example Ni, Fe, Mn, Co or combinations thereof. It will be understood that seed layer 20 is optional and is included in this preferred embodiment for illustrative purposes. Also, the positioning of anti-ferromagnetic layer 30 is for

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fabrication convenience with many other possible configurations available.

A first magnetic region 55 having a resultant magnetic moment vector 57 is positioned on the anti-ferromagnetic layer 30. An electrically insulating layer 70 is placed on first magnetic region 55 and a second magnetic region 135 having a resultant magnetic moment vector 87 is positioned on electrically insulating layer 70. Electrically insulating layer 70 behaves as a tunneling barrier junction. It will be understood that electrically insulating layer 70 can include multiple insulating layers, but is shown as one layer for illustrative purposes.

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Anti-ferromagnetic layer 30 pins resultant magnetic moment vector 57 unidirectionally along a preferred magnetic axis unless sufficient magnetic field is supplied to overcome the pinning action of layer 30. Generally, anti-ferromagnetic layer 30 is thick enough to insure that spurious signals and normal cell writing signals will not switch resultant magnetic moment vector 57.

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In the preferred embodiment, fixed magnetic region 55 includes a synthetic anti-ferromagnetic layer material which includes a tri-layer structure of an anti-

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ferromagnetic coupling spacer layer 50 sandwiched between
a ferromagnetic layer 60 and a ferromagnetic layer 40.
However, it will be understood that magnetic region 55
can include a synthetic anti-ferromagnetic layer material
5 other than a tri-layer structure and the use of a tri-
layer structure in this embodiment is for illustrative
purposes only. Further, magnetic region 55 is a fixed
ferromagnetic region, meaning that resultant magnetic
moment vector 57 is not free to rotate in the presence of
10 a moderate applied magnetic field and is used as the
reference layer.

A free magnetic region 135 includes a synthetic
anti-ferromagnetic layer material which includes N
15 ferromagnetic layers that are anti-ferromagnetically
coupled, wherein N is a integer number greater than or
equal to two. In the embodiment shown here for
simplicity, N is chosen to be equal to two so that
magnetic region includes a tri-layer structure which has
20 an anti-ferromagnetic coupling spacer layer 90 sandwiched
between a ferromagnetic layer 80 and a ferromagnetic
layer 100. Ferromagnetic layers 80 and 100 each have
thicknesses 81 and 101, respectively. Further, anti-
ferromagnetic coupling spacer layer 90 has a thickness
25 86. It will be understood that the synthetic anti-
ferromagnetic layer material in magnetic region 135 can
include other structures with a different number of

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ferromagnetic layers and the use of a tri-layer structure
in this embodiment is for illustrative purposes only.
For example, a five-layer stack of a ferromagnetic layer/
anti-ferromagnetic coupling spacer layer/ ferromagnetic
5 layer /anti-ferromagnetic coupling spacer layer/
ferromagnetic layer could be used, wherein N is equal to
three.

Generally, anti-ferromagnetic coupling spacer layers
10 50 and 90 include elements Ru, Os, Re, Cr, Rh, and Cu, or
combinations thereof. Further, ferromagnetic layers 40,
60, 80, and 100 generally include alloys of Ni, Fe, Mn,
Co, or combinations thereof. Ferromagnetic layers 80 and
100 each have a magnetic moment vector 85 and 105,
15 respectively, that are usually held anti-parallel by
coupling of anti-ferromagnetic coupling spacer layer 90.
Also, magnetic region 135 has a resultant magnetic moment
vector 87. Resultant magnetic moment vectors 57 and 87
are oriented along an anisotropy easy-axis in a preferred
20 direction. Further, magnetic region 135 is a free
ferromagnetic region, meaning that resultant magnetic
moment vector 87 is free to rotate in the presence of an
applied magnetic field.

25 While anti-ferromagnetic coupling layers are
illustrated between the ferromagnetic layers in magnetic
regions 55 and 135, it will be understood that the

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ferromagnetic layers could be anti-ferromagnetically
coupled through other means such as magnetostatic fields
or other features. For example, when the aspect ratio of
a cell is reduced to five or less, the ferromagnetic
5 layers are anti-parallel coupled from magnetostatic flux
closure. In this case, any nonmagnetic spacer layer that
breaks the ferromagnetic exchange between layers will
suffice. However, in the preferred embodiment, the
adjacent ferromagnetic layers are anti-ferromagnetically
10 coupled by sandwiching anti-ferromagnetic coupling
material between each adjacent ferromagnetic layer. One
advantage of using a synthetic anti-ferromagnetic layer
material is that the anti-parallel coupling of the
magnetic moment vectors prevents a vortex from forming at
15 a given thickness where a vortex would be formed if using
a single layer.

Further, during fabrication of scalable
magnetoresistive tunneling junction memory cell 5, each
20 succeeding layer (i.e. 20, 30, 40, etc.) is deposited or
otherwise formed in sequence and each cell may be defined
by selective deposition, photolithography processing,
etching, etc. in any of the techniques known in the
semiconductor industry. During deposition of at least
25 the ferromagnetic layers 80 and 100, a magnetic field is
provided to set an easy magnetic axis for these layers
(induced anisotropy). This anisotropy axis can also be

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set subsequent to deposition by annealing in the presence
of a magnetic field.

The number N of ferromagnetic layers in free region
5 135 can be adjusted such that the magnetic switching
volume of free region 135 remains substantially constant
or increases as the device is scaled laterally to smaller
dimensions. Thus, the magnetic switching volume of MRAM
device 5 can be controlled and, consequently, the bit
10 error rate can be minimized. Thicknesses 81 and 101
and/or the materials of the layers are chosen so that a
magnetic field needed to switch magnetic moments 85 and
105 remains substantially constant (the term
"substantially constant" is intended to include moderate
15 increases) as the device is scaled laterally. Because
the N ferromagnetic layers can be chosen such that there
is no change in the magnetic moment balance ratio M_{br} , the
switching field H_{sw} remains constant for a circular plan.
The total energy barrier for magnetic moment vector
20 reversal increases since each individual ferromagnetic
layer must overcome its induced anisotropy to reverse,
thereby increasing the effective volume without
increasing H_{sw} . For a bit shape with aspect ratio greater
than one, the volume can be increased while minimizing
25 the increase in switching field by appropriate choice of
moment balance in the adjacent ferromagnetic layers.

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In an alternate embodiment, magnetoresistive tunneling junction memory cell 5 has magnetic regions 55 and 135 that each have a length/width ratio in a range of 1 to 5 for a non-circular plan. When the aspect ratio of free and fixed regions 135 and 55 is less than five, magnetic moment vectors 85 and 105 in magnetic region 135 have a strong tendency to align anti-parallel solely from magnetostatic fringing fields. This magnetostatic coupling therefore allows the replacement of the anti-ferromagnetic coupling layer with a spacer layer that does not allow interlayer exchange. In the preferred embodiment, MRAM device 5 is circular in shape (generally in a cross-section parallel to substrate 10) so that there is no contribution to the switching field from shape anisotropy and also because it is easier to use photolithography processing to scale the device to smaller dimensions laterally. However, it will be understood that MRAM device 5 can have other shapes, such as square, rectangular, elliptical, or diamond but is illustrated as being circular for simplicity.

In a circular plan, a parameter that predominantly sets the switching field is the material's induced magnetic anisotropy, H_k . For typical materials such as NiFeCo, H_k is only about 20 Oe, which is undesirable for MRAM device operation. If a N-layer structure is included in the free magnetic region, then the effective

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anisotropy and switching field, H_{sw} , is amplified
depending on the sub-layer magnetic moment balance ratio
of the individual sub-layer moments such that:

$$H_{sw} = \frac{(M_{85} + M_{105})}{(M_{85} - M_{105})} \cdot H_k,$$

5 where M_{85} , M_{105} are the magnitude of the magnetic moment
vectors in ferromagnetic layers 80 and 100, respectively.

Turn now to FIG. 2 in which a graph illustrates the
effective switching field, H_{sw} , of a tri-layer structure
10 verses thickness 101 of ferromagnetic layer 100. The
graph of the data in FIG. 2 was generated from a bulk,
unpatterned material film, and as such it is
representative of the trend in H_{sw} of circular bit
patterns. Hence, FIG. 2 provides direct evidence of the
15 amplification effect of an unbalanced synthetic anti-
ferromagnetic structure.

In this particular example, thickness 86 of anti-
ferromagnetic coupling spacer layer 90 is chosen to be 7
20 Å and thickness 81 of ferromagnetic layer 80 is chosen to
be 40 Å. Also, in this example, anti-ferromagnetic
spacer layer 90 includes Ru and ferromagnetic layers 80
and 100 include NiFeCo. As thickness 101 of
ferromagnetic layer 100 is varied from approximately 30 Å
25 to 75 Å, H_{sw} varies dramatically in the range of

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approximately 35 Å to 45 Å. For optimal MRAM device
operation, H_{sw} should be approximately in the range
between 50 Oe and 150 Oe. H_{sw} can be set in this range by
varying thickness 101 as illustrated. If thickness 101
5 is set at 40 Å, then H_{sw} will be approximately 225
Oersteds, which is probably too high. If thickness 101
is set at around 43 Å, then H_{sw} will be approximately 75
Oersteds, which is a more ideal value. The important
point is that by adjusting the thicknesses, 81, 86, and
10 101, H_{sw} can be adjusted to a desired value.

Thus, the scalable magnetoresistive memory device
has a magnetic switching volume that can be controlled by
varying N. By adjusting N, the magnetic switching volume
15 can be increased as the MRAM device is scaled laterally
to smaller dimensions. Consequently, the bit error rate
due to thermal fluctuations is reduced. Also, H_{sw} can be
controlled by varying the thicknesses and/or materials of
the ferromagnetic layers. By controlling H_{sw} , the
20 switching field can be adjusted to a desired value
sufficient for MRAM device operation as the device is
scaled laterally to smaller dimensions.

Various changes and modifications to the embodiments
25 herein chosen for purposes of illustration will readily
occur to those skilled in the art. To the extent that

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such modifications and variations do not depart from the spirit of the invention, they are intended to be included within the scope thereof which is assessed only by a fair interpretation of the following claims.

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Having fully described the invention in such clear and concise terms as to enable those skilled in the art to understand and practice the same, the invention claimed is:

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CLAIMS

1. A scalable magnetoresistive tunneling junction
memory cell comprising:

5 an electrically insulating material designed to
form a magnetoresistive tunneling barrier;

a first magnetic region positioned on one side of
the electrically insulating material, the first magnetic
region having a magnetic moment vector adjacent the
10 electrically insulating material;

a second magnetic region positioned on an opposite
side of the electrically insulating material, the second
magnetic region having a magnetic moment vector adjacent the
insulating material and oriented in a position parallel or
15 anti-parallel to the magnetic moment vector of the first
magnetic region, the electrically insulating material and the
first and second magnetic regions forming a magnetoresistive
tunneling junction device, and

at least one of the first and second magnetic
20 regions including a synthetic anti-ferromagnetic layer
material that has a magnetic switching volume, the synthetic
anti-ferromagnetic layer material includes N ferromagnetic
layers which are anti-ferromagnetically coupled, where N is
an integer greater than or equal to two, and the magnetic
25 switching volume is adjustable by changing N to maintain a
sufficient energy barrier to switching for nonvolatile memory

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operation as the magnetoresistive memory element is scaled laterally to smaller dimensions.

2. A scalable magnetoresistive tunneling junction
5 memory cell as claimed in claim 1 wherein the magnetic switching volume is adjusted by increasing N such that the volume remains substantially constant or increases as the magnetoresistive memory element is scaled laterally to smaller dimensions.

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3. A scalable magnetoresistive tunneling junction
memory cell as claimed in claim 1 wherein a sub-layer magnetic moment fractional balance ratio of the one of the first and second magnetic regions remains constant as the
15 magnetoresistive memory element is scaled laterally to smaller dimensions.

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4. A scalable magnetoresistive tunneling junction memory cell comprising:

an electrically insulating material designed to form a magnetoresistive tunneling barrier;

5 a first magnetic region positioned on one side of the electrically insulating material, the first magnetic region having a magnetic moment vector adjacent the electrically insulating material;

a second magnetic region positioned on an opposite
10 side of the electrically insulating material, the second magnetic region having a magnetic moment vector adjacent the insulating material and oriented in a position parallel or anti-parallel to the magnetic moment vector of the first magnetic region, the electrically insulating material and the
15 first and second magnetic regions forming a magnetoresistive tunneling junction device, and

at least one of the first and second magnetic regions including N ferromagnetic layers which are anti-ferromagnetically coupled, where N is an integer number
20 greater than or equal to two, and has a sub-layer magnetic moment fractional balance ratio and the switching field of at least the one of the first and second magnetic regions is adjusted by changing the sub-layer magnetic moment fractional balance ratio such that the magnetoresistive memory element
25 is scalable laterally to smaller dimensions.

24

5. A scalable magnetoresistive tunneling junction memory cell comprising:

a first magnetic region having a resultant magnetic moment vector fixed in a preferred direction in the absence of an applied magnetic field;

an electrically insulating material positioned on the first magnetic region to form a magnetoresistive tunneling barrier; and

a second magnetic region positioned on the insulating material and having a resultant magnetic moment vector switchable between positions parallel and anti-parallel to the resultant magnetic moment vector of the first magnetic region, the electrically insulating material and the first and second magnetic regions forming a magnetoresistive tunneling junction device, and

at least one of the first and second magnetic regions include N ferromagnetic layers which are anti-ferromagnetically coupled, where N is an integer greater than or equal to two, and the at least one of the first and second magnetic regions including a sub-layer magnetic moment fractional balance ratio designed to set a switching field.

6. A scalable magnetoresistive tunneling junction memory cell as claimed in claim 5 wherein the N ferromagnetic layers are anti-ferromagnetically coupled by sandwiching a layer of anti-ferromagnetic coupling material between each adjacent pair of ferromagnetic layers.

25

7. A scalable magnetoresistive tunneling junction memory cell as claimed in claim 5 wherein at least one of the first and second magnetic regions has a magnetic switching
5 volume that remains substantially constant or increases as the device is scaled laterally to smaller dimensions.

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8. A scalable magnetoresistive tunneling junction
memory cell comprising:

a substrate;

an anti-ferromagnetic material supported on the
5 substrate;

a fixed magnetic region positioned on the anti-
ferromagnetic material which includes a synthetic anti-
ferromagnetic layer material, having a resultant magnetic
moment vector which is fixed in a preferred direction in the
10 absence of an applied magnetic field;

an electrically insulating layer positioned on the
fixed magnetic region; and

a free magnetic region positioned on the electrically
insulating layer to form a magnetoresistive tunneling
15 junction device in cooperation with the electrically
insulating layer and the fixed magnetic region, the free
magnetic region including a synthetic anti-ferromagnetic
layer material that includes N layers of a ferromagnetic
material, where N is an integer number greater than or equal
20 to two, and wherein each layer of the N layers of the
ferromagnetic material has a magnetic moment vector where the
magnetic moment vectors of each adjacent layer of the N
layers of the ferromagnetic material are oriented anti-
parallel such that they are anti-ferromagnetically coupled,
25 and a magnetic switching volume of the free magnetic region
that is scalable by increasing N such that the volume remains
substantially constant or increases to maintain a sufficient

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energy barrier to switching for nonvolatile memory operation
and a moment fractional balance ratio of the free magnetic
region that remains substantially constant as the scalable
magnetoresistive memory element is scaled laterally to
5 smaller dimensions.

9. A method of fabricating a scalable magnetoresistive
tunneling junction memory cell comprising the steps of:
- providing a substrate defining a surface;
 - 10 supporting a fixed magnetic region having a
magnetic switching volume and also having a resultant
magnetic moment vector on the substrate, wherein the
resultant magnetic moment vector is oriented in a preferred
direction;
 - 15 positioning an electrically insulating tunneling
junction layer on the fixed magnetic region;
 - positioning a free magnetic region having a
resultant magnetic moment vector and a magnetic switching
volume on the electrically insulating tunneling junction
20 layer, wherein the resultant magnetic moment vector can be
oriented one of parallel and anti-parallel with respect to
the resultant magnetic moment vector of the fixed magnetic
region, the free magnetic region includes a synthetic anti-
ferromagnetic layer material which includes N ferromagnetic
25 layers that are anti-ferromagnetically coupled, where N is an
integer number greater than two and where each N
ferromagnetic layer has a magnetic moment vector and the

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magnetic moment vectors of each adjacent N layer of
ferromagnetic material are oriented anti-parallel; and

adjusting the number of N ferromagnetic layers and
their magnetic moment to optimize the magnetic switching

5 volume as the lateral dimensions of the device are changed
and a sub-layer magnetic moment fractional balance ratio of
the free magnetic region is chosen to provide a magnetic
switching field so that as the device is scaled laterally to
different dimensions, a sufficient energy barrier to
10 switching is maintained for nonvolatile memory operation.

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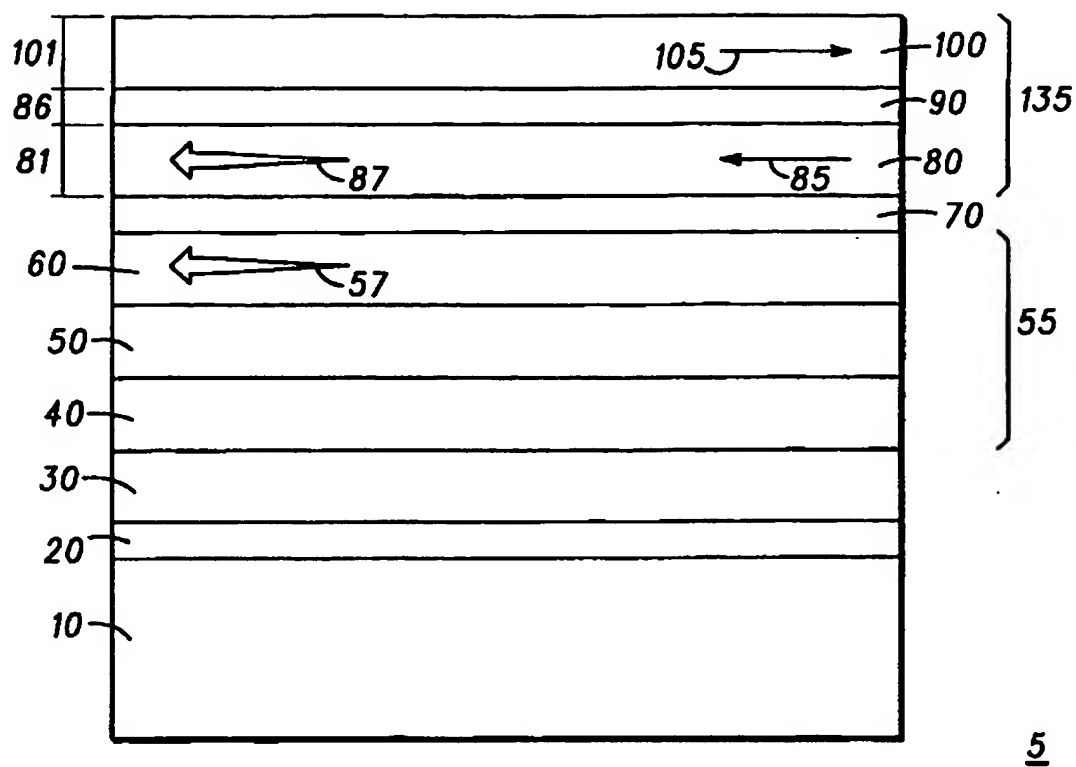


FIG. 1

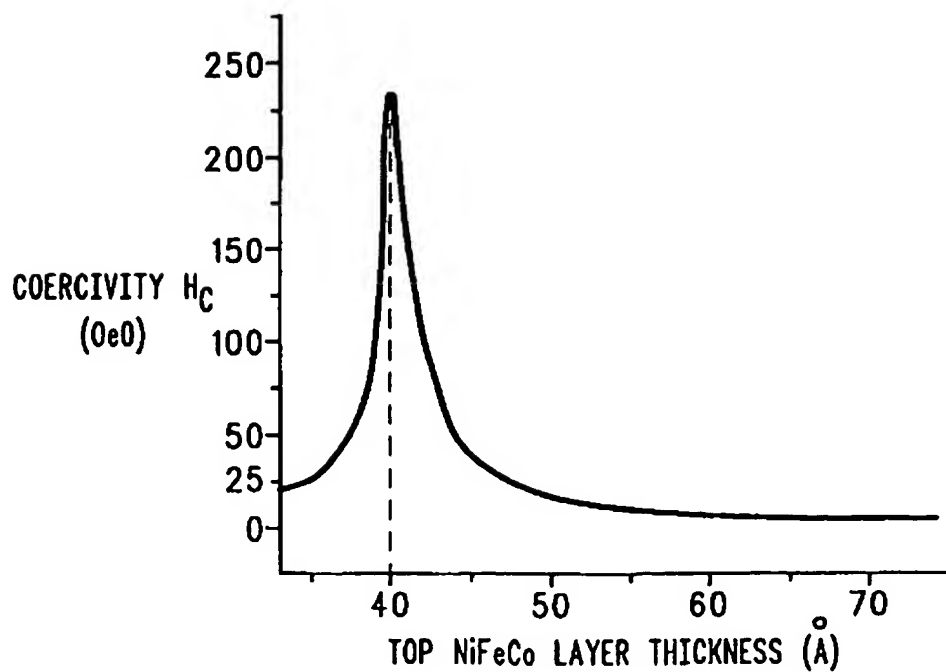


FIG. 2

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G11C11/16 H01F10/32 H01F41/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G11C H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 1 109 168 A (MOTOROLA INC) 20 June 2001 (2001-06-20) page 4, line 16 - line 54; claims 1-3,7,8; figure 1 --- -/--	1 2,3

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents:

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Date of the actual completion of the International search

23 December 2002

Date of mailing of the International search report

23/01/2003

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Decanniere, L

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>DATABASE INSPEC 'Online! INSTITUTE OF ELECTRICAL ENGINEERS, STEVENAGE, GB; UHM Y R ET AL: "Computer simulation of switching characteristics in magnetic tunnel junctions exchange-biased by synthetic antiferromagnets" Database accession no. 7286478 XP002226080 abstract & INTERNATIONAL SYMPOSIUM ON PHYSICS OF MAGNETIC MATERIALS/ INTERNATIONAL SYMPOSIUM ON ADVANCED MAGNETIC TECHNOLOGIES (ISPM/ISAMT2001), TAIPEI, TAIWAN, 13-16 MAY 2001, vol. 239, no. 1-3, pages 123-125, Journal of Magnetism and Magnetic Materials, Feb. 2002, Elsevier, Netherlands ISSN: 0304-8853</p>	1-3
A	<p>DE 198 30 343 C (SIEMENS AG) 6 April 2000 (2000-04-06) page 3, line 37 -page 5, line 37; claims 1,3,5,6,9,12; figures 1-4</p>	1
A	<p>PATENT ABSTRACTS OF JAPAN vol. 2000, no. 06, 22 September 2000 (2000-09-22) & JP 2000 090418 A (TOSHIBA CORP), 31 March 2000 (2000-03-31) abstract</p>	1

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